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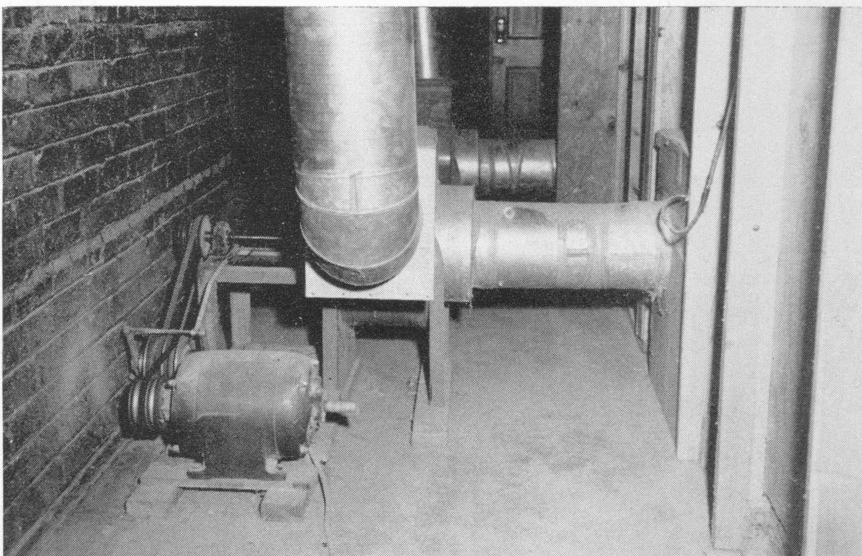

OHIO AGRICULTURAL EXPERIMENT STATION - - - WOOSTER, OHIO

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INTRODUCTION

Air exhausted from a poultry house by conventional ventilation is laden with odor, ammonia, moisture, dust, and feathers (1, 4). It is the function of ventilation to get rid of these wastes. Unfortunately, however, winter ventilation also gets rid of large quantities of heat with the result that the house is sometimes undesirably cold. In many houses, it is impossible to ventilate sufficiently to get rid of these wastes as fast as they are produced without cooling the house below freezing during very cold weather. Thus, the common practice is to allow these wastes to accumulate by reducing ventilation to conserve heat and thereby keeping the house warmer.

Since the development of dependable, compact refrigeration systems, the idea of either removing the moisture from the house by use of a dehumidification cycle while using a very low ventilation rate, or— using a higher ventilation rate, but retrieving the heat from the exhaust air and returning it to the house, has appealed to many engineers and poultrymen. In either case, the air from the house must be passed over a cooling coil which is operating below the dew point of the exhaust air. Unless this air is filtered adequately, the dust will rapidly plug, and render inoperative, any heat exchanger commonly used on refrigeration equipment. A number of investigators have tried air tempering equipment to modify the humidity or conserve the heat. Many of them report that dust has been a troublesome nuisance or even a deterrent to successful operation (2, 3, 4, 5, 6).

In this study, no attempt has been made to justify the economic importance of air conditioning equipment for use in poultry houses. In fact, research attempting to evaluate the economical suitability of air conditioning equipment was being hampered and delayed because of the operational difficulties caused by the dust and feathers in the air. For this reason, a research project aimed at the solution of the problem of filtration of poultry house air was undertaken.

OBJECTIVES OF THE STUDY

Specifically, this study was established to:

1. Determine the nature and characteristics of the dust problem with reference to heat exchanger performance.
2. Evaluate existing means of automatically filtering air that would possibly be adaptable to the filtering of poultry house air.
3. If necessary, develop new methods of automatically filtering poultry house air and/or develop new heat exchangers to handle poultry house air.

METHOD OF STUDY

The two fundamental procedures established at the beginning of this investigation were: 1. All tests would be run in poultry houses where birds were loose on old corn cob litter and where large volumes of dust would be produced and dispersed naturally by the birds under normal conditions, and 2. The evaluation of the worth of a filter system would be made on the basis of its ability to protect a typical heat exchanger operating under normal conditions of heat transfer to or from the poultry house air. Heat exchange performance of the exchanger over long periods of time was determined to be the number one criteria for evaluation of the filtering system under test.

SELECTION OF POSSIBLE FILTERING PRINCIPLES FOR TRIAL

Tests, with an air sampler, made in several animal and poultry shelters led to the conclusion that there were many different sizes and forms of dust and debris in this air—feathers, hair, list[1], feed dust, bits of litter, down, powdered feces, dandruff, etc. It became apparent that no one piece of commercial equipment using any one filtering principle could automatically remove all of these impurities. No plans for construction of non-commercial equipment to completely solve the air filtration problem for air conditioning equipment were available.

Consideration was given to the possibility of changing the design of heat exchangers to place smooth tubes or plates far enough apart to allow all of this air-borne material to pass through. The principles of heat transfer were applied to the problem in a mathematical analysis

[1]In this bulletin "list" refers to the barbs and barbules broken from the quills of feathers.

and it was soon determined that the cost and space requirements for this type of heat exchanger would be prohibitive. The decision was made to attempt to find a workable means of automatically protecting a fin-coil heat exchanger with continuous plate fins such as is used on air conditioning equipment.

After many observations of the nature of the dust clogging of heat exchangers, it appeared that the critical point was the leading edge of the exchanger and that fibrous debris was the primary cause of clogging. Consultation with air conditioning and air filtration experts tended to support this premise, namely: If the long fibrous material which rapidly clogged the leading edge of the heat exchangers could be filtered out, there was a good likelihood that the fine dust would not greatly interfere with heat exchange performance, assuming that air flow through the exchanger could be maintained. This premise was based on experience in industry with other air filtration problems.

Several types of commercial air filters were considered. Electronic precipitation was ruled out because of the initial cost and technical maintenance required and because its greatest usefulness is with fine dust rather than coarse fibrous material. Certain types of air washers and wet filters were considered but ruled out because of the air humidification resulting from their use and because of initial cost and troublesome maintenance. Ordinary dry glass fiber or aluminum shaving filters such as used as furnace filters were ruled out because of the very frequent maintenance required (2, 5).

FILTERS TESTED

Test I—Engineers from a manufacturer of air filtering equipment suggested the use of dry paper filter equipment to solve the dust problem. The equipment which they furnished for testing consisted of a duct with a calibrated orifice plate, a filter assembly, and a blower. The filter assembly consisted of a stainless steel belt for supporting the filter paper across the airstream, a motor and drive for turning the belt, a clean paper roll above the airstream and a dirty paper roll below the airstream, and a pressure switch which functioned to roll clean paper into the airstream automatically as it was needed. See Figure 1.

In this test, the heat exchanger was mounted on the downstream side of the blower. After several test runs were attempted with this laboratory model, it became apparent that the seals around the belt were not tight and some debris was bypassing the filter paper. The attempts were halted pending replacement with a new model.

Test II—The possibility of making a filter assembly with the filter media supported on the upstream edge of the heat exchanger itself was investigated. One-hundred mesh copper screen was fitted into a filter test assembly as shown in Figure 2. Twin assemblies were made to test filter performance with one heat exchanger operated dry and one heat exchanger cooled below the dew point of the air. The copper screens were made to be rolled up and down through the air stream with a vacuum nozzle cleaning the screen by reverse-flushing as the screen rolled out of the airstream in either direction. An alternate scheme of operation was to hold the copper screen stationary and move a full-width vacuum nozzle up and down on the upstream side of the screen by some mechanism such as a level-wind screw. With the latter method of operation, the vacuum cleaning nozzle had to overcome the suction of the blower as well as provide suction to dislodge the dust fibers.

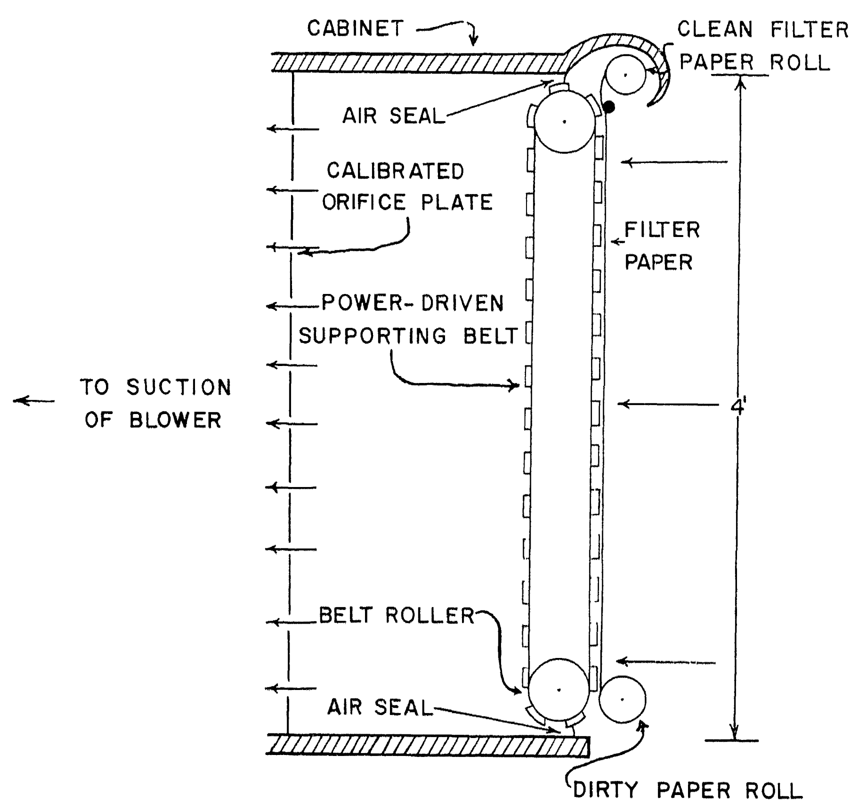

Fig. 1.—Schematic of Automatic Paper Filter.

Test III—A new, larger model of the automatic paper filter assembly, with improved air seals, was again tried. See Figure 3. In this test, the heat exchanger was located between the filter and the blower. During this run the filter performance was evaluated by testing the heat exchange performance of an exchanger protected by the filter and supplied with hot water.

Test IV—An assembly for determining the effect of filtered air versus unfiltered air upon a wet heat exchanger was made as shown in Figure 4. In this test, the unfiltered air was moved by a common ventilating fan while the filtered air was drawn through the other heat exchanger by a backward-curved-blade blower. Both exchangers were cooled below the dew point of the air by water circulated from a 3 hp water cooler.

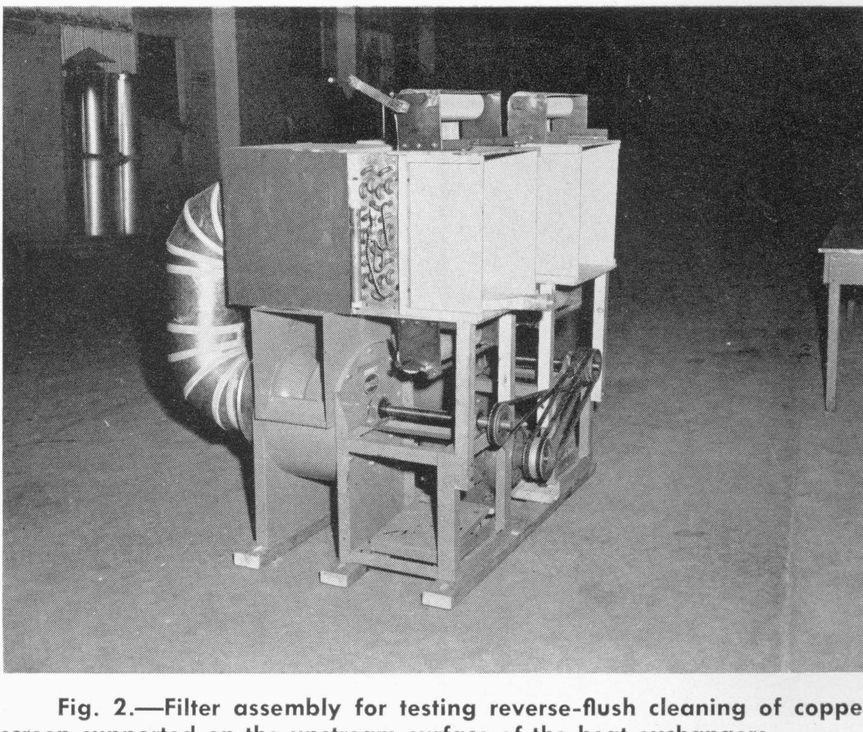

Fig. 2.—Filter assembly for testing reverse-flush cleaning of copper screen supported on the upstream surface of the heat exchangers.

Test V—In this test, an unconventional method of filtering was tried. In the operation of the automatic paper filter, it was of course true that the thicker the dust collected on the paper, the better was the filtering action. This and other considerations suggested the question of whether the litter itself could be used as a filter. Calculations showed that, if the whole area of litter were used, the maximum required rate of movement of air through the litter would be about 3 cfm/ft.^{2}, if the maximum recommended ventilation rate were used with no air recirculation. If a heat exchanger were used to remove moisture from the ventilating air and/or return heat to the house, a lesser rate than this could be feasible.

A test was run in which both the filtering characteristics and the ventilating characteristics of "down-draft" removal of air through the litter was evaluated. The litter was supported on a false floor as shown

Fig. 3.—Filter assembly used for test runs of Test III and Test VI.

in Figure 5. Air was pulled out between the floor joists and collected in a duct which led to a blower inlet. This blower removed the air at a rate of 1.0 cfm/ft.^{2} to 1.75 cfm/ft.^{2}. For purposes of evaluation of the quality of ventilation provided, a check pen containing similar bird population, area, litter, and equipment was ventilated with a blower whose inlet was placed about 24″ above the litter. The evaluation of this down-draft principle as a ventilation system apart from its filtering characteristics is reported in a separate publication (7). Evaluation of the filtering characteristics of this system was made with an air sampler.

Test VI—Further tests were made of the down-draft exhaust system wherein the litter was supported on crushed stone. See Figure 6. Air was moved through the litter at about 3.0 cfm/ft.^{2}, then through a test heat exchanger and into a blower inlet. At the same time, air was

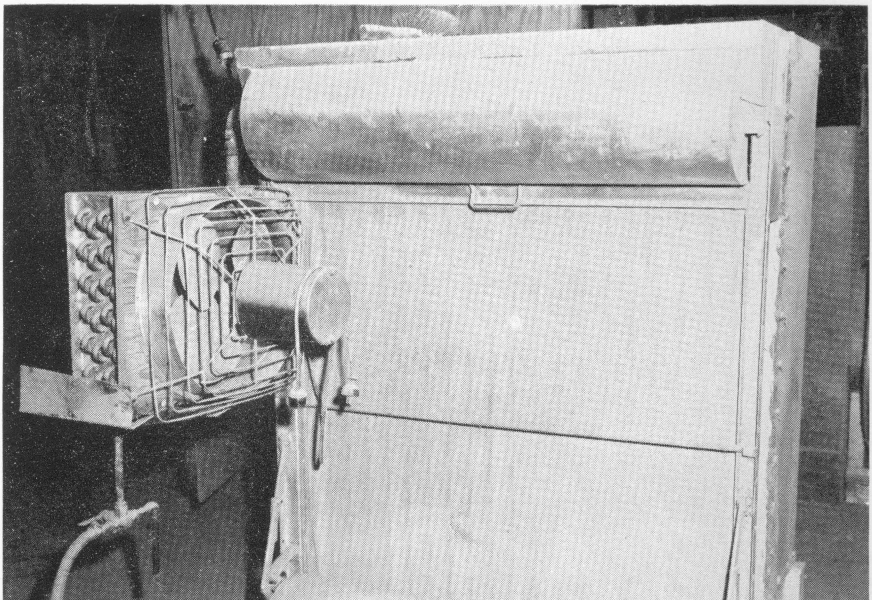

Fig. 4.—Assembly of Unit Cooler handling unfiltered air and paper filter protecting a similar heat exchanger inside the cabinet.

taken from above the same litter, filtered through the paper filter, pulled through a similar heat exchanger and into a similar blower. Both heat exchangers operated below the air dew point. Both blowers discharged the cool, nearly-saturated air back into the test pen of birds. This test was run from June to November. Average bird population was about 1.75 pounds of bird/ft.^{2}.

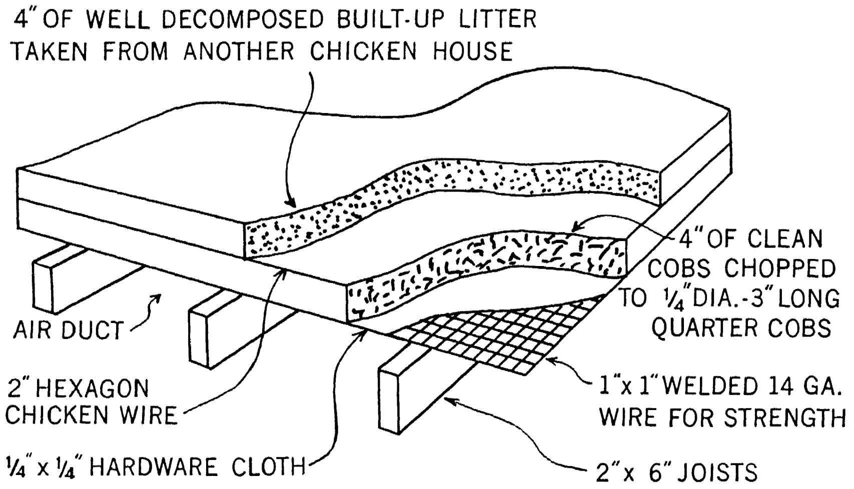

Fig. 5.—This drawing shows the arrangement of air ducts, floor and litter components used.

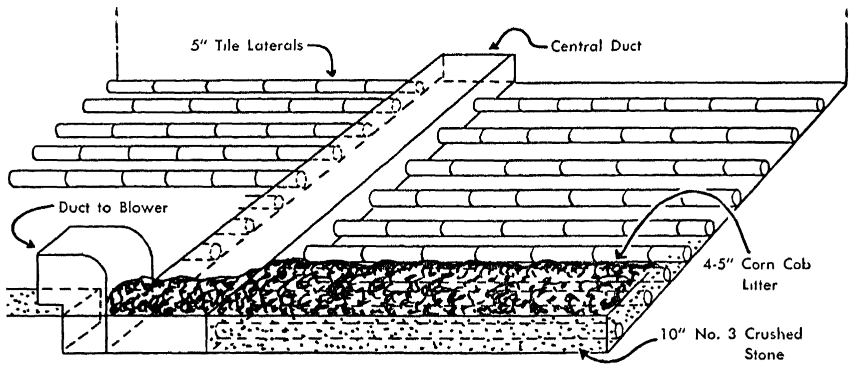

Fig. 6.—These are the air-collecting ducts used in pulling ventilating air through litter supported on crushed stone.

OBSERVATIONS AND RESULTS

Test I—First test of the automatic paper filter with a dry exchanger on the discharge side of the blower.

In this test, the paper filter cabinet had leaky air seals. However, some degree of protection was afforded the heat exchanger. Air was moved through the paper at a rate of about 200'/min. from a broiler house. The static resistance of the paper filter was regulated at 1.7"H_2O. Under these operating conditions three weeks of reliable data were obtained. During this period, the heat exchanger performance of the exchanger dropped about 5%. The leading edge of the exchanger did not mat over with dust, but the air flow dropped about 5% due to the fine dust and a few feathers that came through the leaky air seals. See Figure 7. In this test, paper was used at a rate which would have cost about $2.50/month.

Test II—Copper screen filters mounted directly on the leading edge of the heat exchangers.

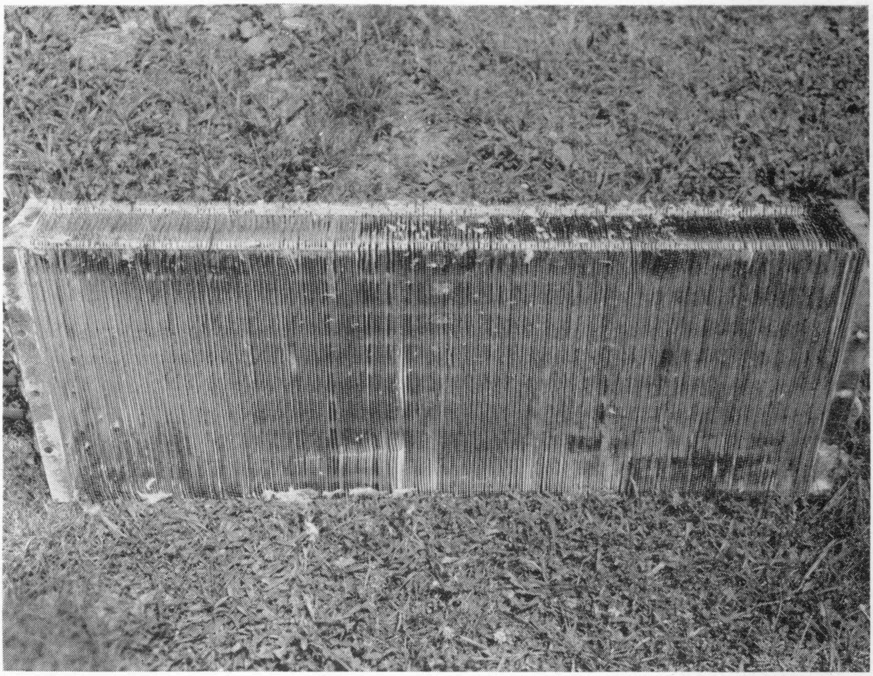

Fig. 7.—Upstream side of the heat exchanger after three weeks of operation in Test I.

The intent of this test was to determine the effect of condensation upon the rate of dust clogging as well as try the principle of reverse flushing while in operation. No refrigeration equipment for cooling the one exchanger was available when the test apparatus was assembled so the test of the effect of condensation had to be postponed. Manual operation of the proposed automatic scanning nozzle for reverse-flushing of the filter screen showed that lint was very difficult to remove from the screen. Because this 100 mesh screen was a woven screen, the lint and down lodged between the wires where they crossed and was very difficult to remove by suction cleaning from either direction. Addition of a brush to the cleaning head improved the performance some. However, this test was terminated due to the small overall promise this system showed.

Test III—Test of improved model of automatic paper filter protecting a dry heat exchanger.

In this test a unit was chosen to express heat exchange performance for purposes of comparison rather than measurement of absolute heat exchange efficiency. This unit was chosen to be the heat transferred in Btu per hour for each pound per hour of hot water supplied to the heat exchanger and for each degree Fahrenheit difference between the entering water temperature and the temperature of the air approaching the exchanger (the initial potential). Water flow rate was confined to a variation of $\pm$ 15% which was compensated for in the unit of heat transfer chosen. Air flow rate over the exchanger varied according to the resistance of the filter (operating on about a 30 minute cycle between 0.85"H_2O and 1.00"H_2O). The average air flow rate was adjusted to be nearly constant at about 1600 cfm over the duration of the test. An exchanger of 5.0 ft.^{2} area was used. Since air flow rate was a function of the filtering system under test, no attempt was made to compensate for this variation in the analysis of the data.

The data are presented in Figure 8. Taking the entire 83 day test, a regression line fitted to the data shows a drop in heat exchange performance of 0.00120 units per day of operation. However, the data can also be interpreted as requiring a regression curve or two regression lines for a "best fit". The previous held opinion based on the experience of air filtration men in industry is supported by this latter interpretation. Visual observations during this test indicated that the initial build up of dust within the plate fins is rather rapid. At some time, however, the build up on the fins slows down considerably. This point of time apparently is when the passages are reduced in cross-section sufficiently to cause the air velocity to increase (assuming constant flow rate) to a

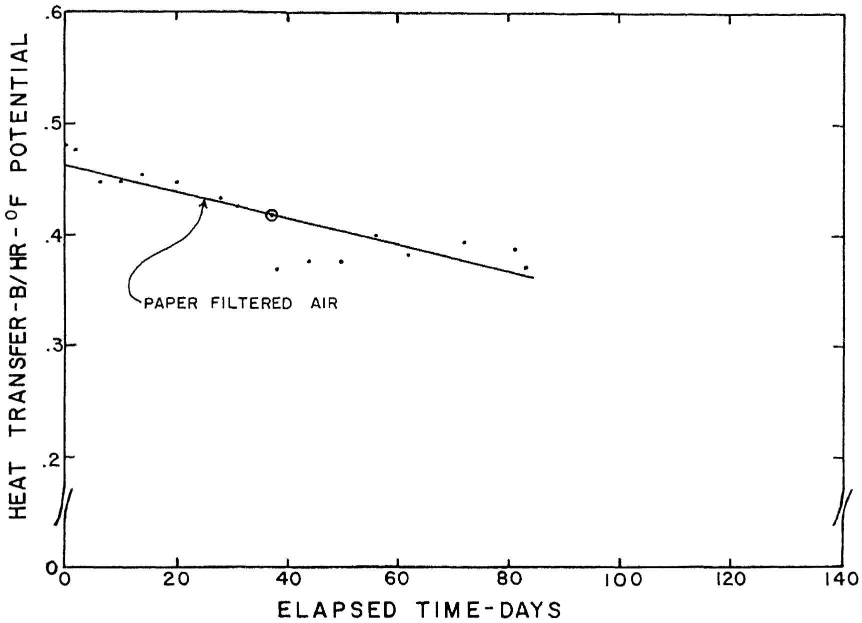

Fig. 8.—Heat transferred for each pound per hour of water circulated through the heat exchanger in Test 3. Water temperature above air temperature.

level where the dust is carried on past the restriction. Thus, if air flow rate is maintained in spite of the increased resistance, the rate of plugging and corresponding rate of loss in heat exchange performance may be reduced. Looking at the data of Figure 8 in this light, it would appear that there are two phases to this plugging of a dry fin-coil heat exchanger. During the first phase, which lasted about 35 days, the data indicated a drop of about 0.0020 units per day. The second phase then would have a drop of about 0.00080 units per day.

At the end of the 83 days, the duct between the filter and the exchanger was opened to allow unfiltered air directly to the exchanger. The increased air flow (blower speed remained the same—total system resistance greatly reduced) blew the dry dust out of the exchanger and the performance was increased briefly. However, the leading edge of the exchanger began to plug and soon the heat exchange performance dropped sharply as the air flow rate decreased sharply.

During this test run another interesting fact was determined. Using an upper limit of 1″H_2O on the filter resistance and handling 1600 cfm of poultry house air through this 11.5 ft.^{2} filter, 0.68 lb./24 hours of dust was removed by the filter paper.

A short test of a 1.6 ft.^{2} exchanger handling air from the same house was made. The air was pushed through the exchanger at an initial velocity of 650′/min. by a propeller fan. Unfiltered air was used. Hot water was circulated in the exchanger. Within two weeks, the average air velocity through the exchanger had dropped to 440′/min. with the center entirely plugged. With the exchanger on the downstream side of the fan and the rather high velocity through the exchanger in front of the tips, the dust had filled the exchanger from trailing edge to leading edge.

Test IV—Unfiltered, fan-propelled air versus filtered blower-propelled air over similar heat exchangers operating below air dew point temperature.

Two 1.6 ft.^{2} cross-section fin-coil heat exchangers were used. The operation of the water chiller for cooling water for the exchangers was lacking in dependability and little quantitative data could be collected for a continuous study of the change of performance with time. However, some observations of value were made.

Using the same exchanger and fan as referred to in Test III in unfiltered air, and obtaining condensation more than one-half of the time, results were far different from those obtained with a dry exchanger in unfiltered air. This time the fins were oriented vertically to try to get some washing action from the condensate. However, this effect was not apparent. After ten days, the air flow from the propeller fan through the unprotected exchanger was nil. The heat transfer had dropped to less than 10% of its initial value. The leading edge, though almost dry because the condensation did not form until about the middle of the exchanger, became so densely matted with lint and dust that it could not be cleaned by high pressure air or water. The downstream side is shown in Figure 9. It was concluded that condensation did not materially influence the rate of clogging the leading edge of the unprotected exchanger but did hasten the clogging between the fins in the body of the exchanger. The intermittent condensation had caused the lint and dust to adhere so tightly that simple cleaning after the dust had dried was impossible.

The heat exchanger protected by the dry paper filter operated for 65 days with very little decrease in heat exchange performance. At the end of the run, visual inspection revealed no debris matted on the leading edge of the exchanger. No passages were clogged even though the fins had been oriented horizontally.

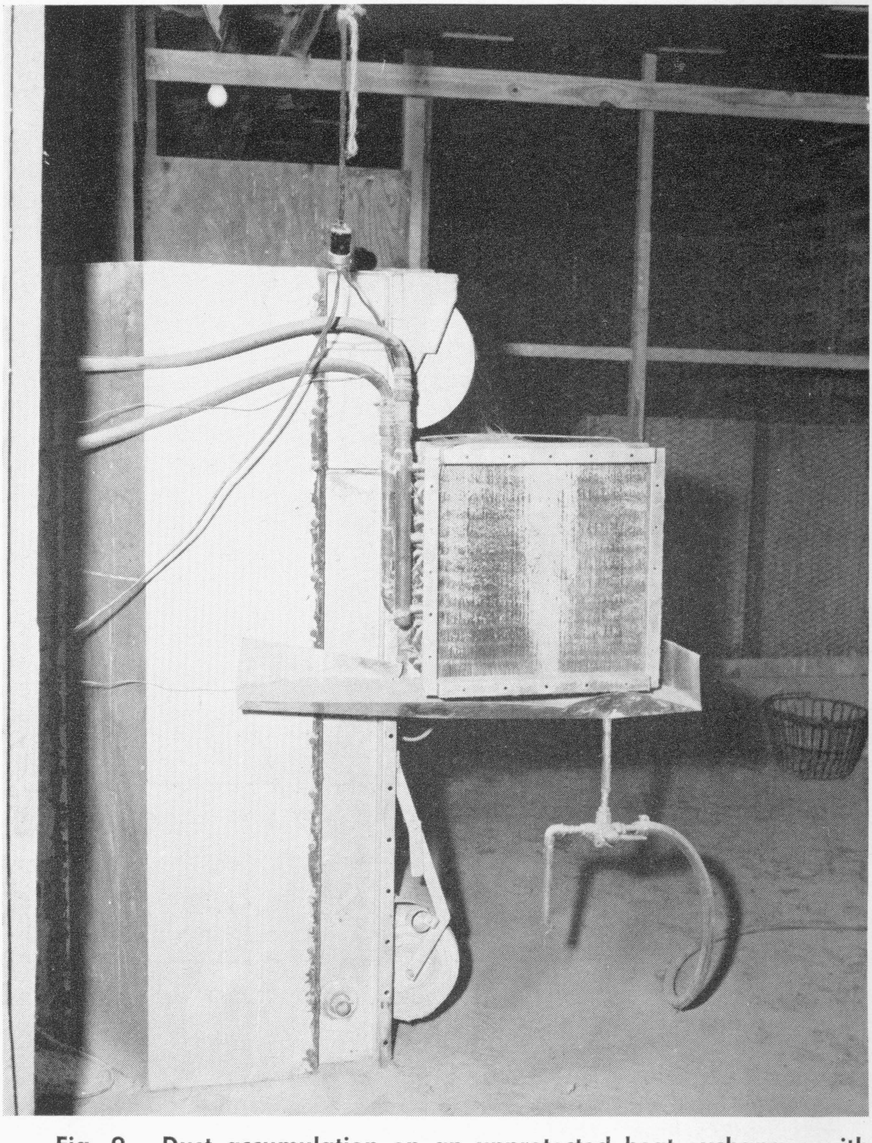

Fig. 9.—Dust accumulation on an unprotected heat exchanger with air moved by a propeller fan immediately behind the exchanger.

Test V—Sampler evaluation of the filtering characteristics of litter.

During the course of this pilot study of air removal through deep litter, several samples of this air were tested for dust content. A sampler with a target of paper similar to that used on the dry paper filter previously described was used to evaluate the dustiness of the air. The test air was passed through the paper target at a near-uniform rate and the resistance of the target measured at intervals of time. Figure 10 shows the results of these tests.

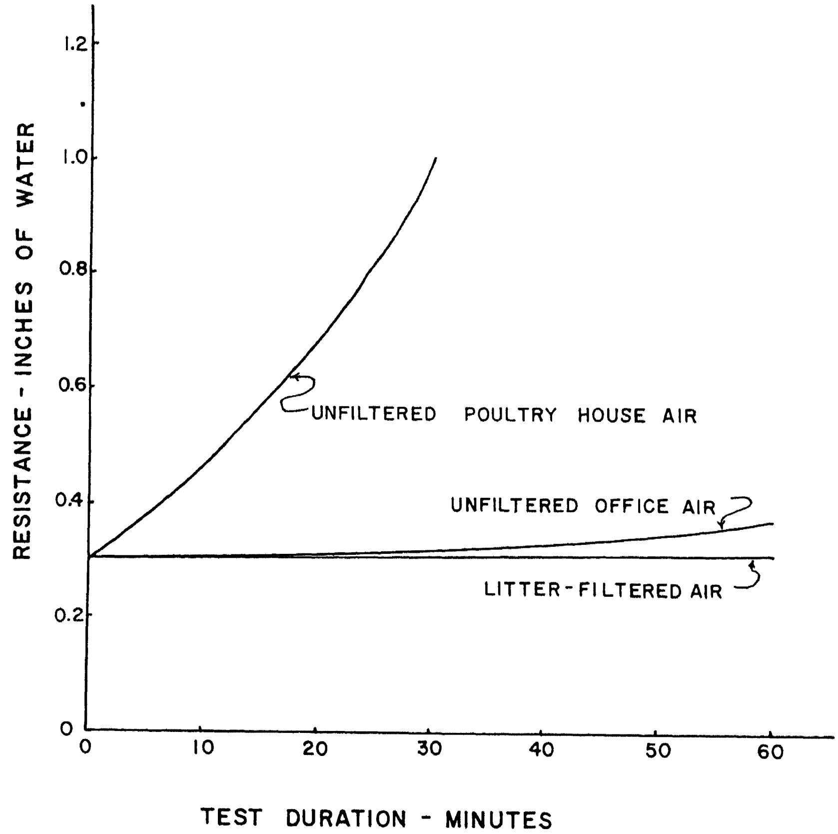

Fig. 10.—Increase in resistance indicates dust content of the air tested.

This showed that the air coming through the litter was virtually dust-free. Of course, it was damp, ammonia laden, and foul-smelling.

During this test run it was necessary to stir the litter every 7-10 days in winter and every 2-3 weeks in summer to keep the resistance below 1.0″H_2O. Air samples were taken during this stirring with the result that practically no dust came through with the air. Even though it was considerable effort to build a false floor for the litter and it required labor to stir the litter to maintain low resistance, the system was believed to be worthy of further study.

Test VI—Heat exchanger evaluation of cleanliness of litter-filtered air versus paper-filtered air with both exchangers continuously below the air dew point.

Figure 11 shows the data from this test. The regression line shows a drop of 0.00141 units per day for the exchanger protected by the automatic paper filter. The drop in performance of the heat exchanger in the air stream of the litter-filtered air is 0.00033 units per day. This shows the protection from the litter to be considerably better than the

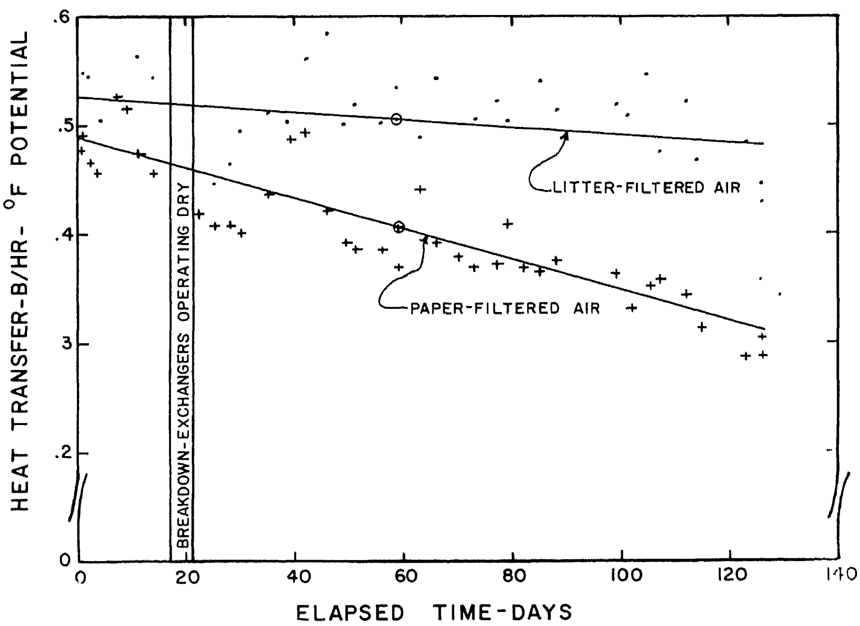

Fig. 11.—Heat transferred for each pound per hour of water circulated through the two heat exchangers in Test 6. Water temperature below air dew point.

protection afforded by the paper filter. However, during this test run, the paper filter operated entirely automatically whereas the litter required stirring every 3-5 days to maintain resistance less than 1.0"H_2O. The litter resistance thus varied from about .70"H_2O to 1.0+"H_2O on a 3-5 day cycle. The paper filter operated between 0.80"H_2O and 0.96"H_2O. Similar air flows were maintained through the similar heat exchangers for the first six weeks of the test. After six weeks, the air flow rate through the paper filter dropped off rather steadily until the end. The rate held essentially constant through the litter filter with respect to test duration, but varied considerably with respect to litter air resistance (3-5 day cycle). The air flow rate through the paper filter at the end of the test was approximately 40% of the initial rate.

The resistance of the exchangers was measured after the end of the test by a special test run. At an air flow rate of about 200 cfm/ft.^{2} of heat exchanger area, the resistance of the exchanger used with the paper filter was 1.5"H_2O and the resistance of the other exchanger was 0.30"H_2O. Figure 12 shows the heat exchangers after removal from the ducts.

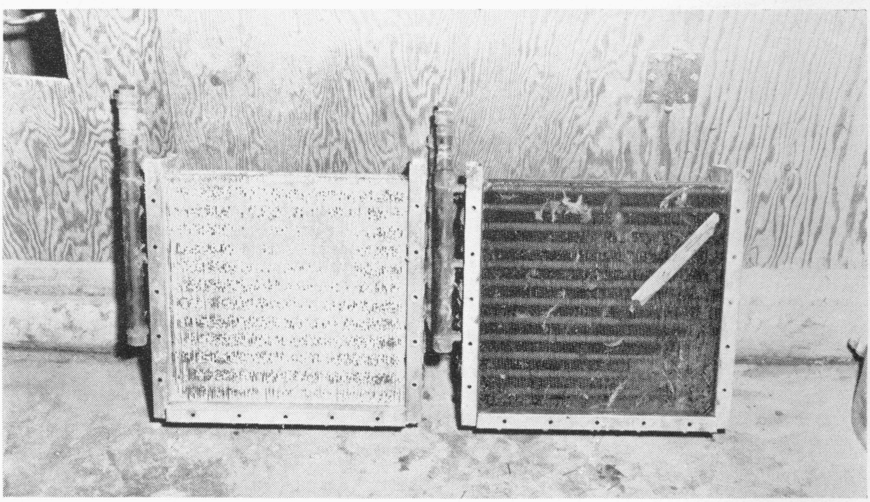

Fig. 12.—Heat exchangers after 128 days of operation. Right one handled litter-filtered air. Left one handled paper-filtered air. Left one still retained 66% of initial heat exchange efficiency with 40% of the initial air flow rate.

In Figure 11 it may be seen that the performance of the exchanger handling litter-filtered air was initially and generally higher than the other exchanger performance. This was due to the evaporative cooling of the air as it passed through the litter resulting in it being nearer the dew point at the leading edge of the exchanger than the air passing through the paper filter.

General—Between all of these tests with the automatic paper filter, three different kinds of one-ply filter paper were used intermittently. These were "moisture-resistant" paper, "ordinary" paper, and glass fiber "paper". On the basis of observation, it is believed that they would rank as follows when used to filter poultry air to protect a fin-coil exchanger:

"Moisture-resistant"—Most effective
"Ordinary"—Almost as effective
Glass fiber "paper"—Not nearly as effective

CONCLUSIONS

1. This research, in general, supports the opinion that it is more important to do a good job of filtering out the lint, feathers and debris than it is to filter out the fine dust for passage of air over fin-coil heat exchangers.

2. Apparently the decrease in heat exchange performance of a fin-coil exchanger operating in poultry house air is much more a function of air movement through the exchanger than it is a function of any insulting effect of fine dust. In all tests, heat exchange performance could be maintained if air flow rate could be maintained against the rising resistance. Heat transfer performance could still be maintained with a heat exchanger that appeared very dusty, so long as the leading edge was not matted to prevent partial air flow.

3. It would be impractical to try to design a heat exchanger for refrigerant gases which would be immune to plugging by unfiltered poultry house air.

4. The litter filter proved to be the most effective filter investigated. This was probably due mostly to its relatively great thickness with respect to most conventional filters. The power required to move the air was no more than that required with the automatic paper filter,

due to the very low velocity of the air moving through the litter. However, the labor required to keep the litter resistance low is a sizable factor to consider. The use of this filter system is, of course, restricted to deep-litter poultry management systems and would best be considered if extremely clean air is desired.

5. The automatic paper filter proved to be quite effective in filtering poultry house air. After minor alterations, its performance was automatic and trouble-free. The application of this principle appears to be the best practical solution to the problem of automatic filtering of poultry house air.

6. It is very important to use fans or blowers with good air delivery against pressures up to 2-3″H_2O when moving filtered air through fin-coil heat exchangers.

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